C.S. Jarvis

Influence of Repeated Stresses in Concrete and Cement.

Thesis (B.S.)

Univ. of Missouri

Columbia, Mo.

1906

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Influence of Repeated Stresses ~~on the Strength of Reinforced Concrete.~~ in Concrete and Cement

By

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Object.

While laboratory tests on concrete and cement specimens broken with single applications of loads may give good comparative results, they do not furnish much information regarding the behavior of the material in actual practice, where from two-thirds to one-sixth of the load that would cause rupture may be applied successively a number of times before the hardening process is well developed. It was for the purpose of inquiring into the effects of repeated stresses on the compressive and tensile strength of neat cement, and the bonding strength of concrete on steel, that the following tests were made.

Materials.

The cement used was of four different brands--- Universal, Alma, Vulcanite, and Iola, all of which gave good results under standard tests for setting, tensile and compressive strength, and soundness as determined by pats in air and pats in water for ninety days.

The steel used was Ransome 3/8" twisted bars; Johnson 3/4" corrugated bars, Rogers-Shears flat corrugated bar, 1/4" section; round 3/4" rods; Ransome truss, and Kahn

trussed bar. The sand used was Hinkson Creek sand, giving a void test of 40%; the stone was limestone, crushed to pass a one and one-half inch ring, and retained on a 1/4" mesh; the cement, sand, and concrete were spread together in the box and turned twice dry; then water was added, and the mass was turned three times. The consistency was such as to cause the surface to quake and flush with water after thorough ramming. Concrete blocks No. 16-18, 22, 27-34, and 38, however, were mixed as follows: The cement and sand were mixed dry until of a uniform color; then water was added and the paste was turned four times, then the previously wet stone was added and the mass turned three times. A comparison of results from the blocks mixed in the two ways develops no material difference in strength.

Methods.

In testing cement briquettes and cubes, and concrete blocks, two or more specimens were usually broken by single applications of stress, in order to establish a mean modulus of rupture. Then varying percentages of this mean stress were applied a number of times, the minimum loading between consecutive applications being about five percent of the maximum repeated stress. On the data sheets, the number of repetitions is indicated as a co-efficient of the stress per

square inch.

The rate at which the load is applied will be seen to affect the ultimate strength very materially. For applying single loads, or the first load of a series, the time consumed was about two minutes for briquettes and cubes of neat cement, and three minutes for concrete blocks with steel imbedded. In repeating stresses the intervals required for relieving and again applying the load were about fifteen seconds for briquettes and cubes, and two minutes for steel and concrete.

For breaking the briquettes the testing machines used were the Fairbanks and Olsen; and for cubes and blocks the Olsen 20,000, Olsen 30,000, and Rieble 50,000# machines.

The method of testing bonding strength of concrete on steel was to apply tension to the steel bar on the Olsen 30,000 machine; the block had been molded with the center of the bar at the center of the cube, and it was forced along the rod by the split end of a lever, arranged to avoid eccentric thrust.

The fulcrum for the lever rested on the weighing platform of the Olsen 20,000 machine; and the recorded weight, with the ratio of lever arms and known weight of lever, gave the amount of thrust. This caused an added tension in the steel, as the initial tension was maintained constant, in

addition to the thrust.

When the bond was tested without initial tension in the steel, the bar was simply drawn from the block on the Olsen 30,000 machine.

The manner of loading the beams in clearly shown on the accompanying photographs. The centers of the blocks distributing the load were eight inches and twenty-four inches respectively each side of the center of the beams.

The span was seven and one-half feet between supports, one of which rested on the platform of the Riehle 50,000 machine.

The length of beams was eight and one-half feet; depth, twelve inches; depth to center of gravity of steel ten and three-fourths inches; width, eight inches.

THESIS DATA - TENSILE STRENGTH OF NEAT CEMENT - C.S. Jarvis, 1906.

No.	Kind of Cement	Consistency	Age in days	Tensile Strength, Lb. per sq. in. Direct	Average	Repeated	Remarks
1	Universal	Normal	1	198			Briquettes No. 1 to No. 35
2		24%	1	186			were kept in the molds in moist
3			1	168	187		air for one day; then removed
4			7	335			from molds and kept in water
5			7	386			at about 68°Fahr. until tested.
6			7	470	397		
7			29	609			In repeating stresses the minimum
8			29	729	719		is nearly 5% of the maximum.
9			29			89 X 500#	
10	Alma	Normal	1	85			
11		23.7%	1	65			
12			1	62	71		
13			7	410			
14			7	416			
15			7	419	415		
16			39	592			
17			39	719			
18			39	625			
19			39	760	674		
20			39			25 X 500# + 750#	
21			39			125 X 500# + 755#	
22			39			25 X 600# + 760#	
23			39			125 X 600# + 740#	
24			39			27 X 650#	
25	Vulcanite	Normal	1	161			
26		22.7%	1	163			
27			1	111	145		
28			7	445			
29			7	475			
30			7	435	452		
31			37			53 X 402#	
32			7			4 X 402#	
33			37	742			
34			37	760	751		
35			37			25 X 600 + 720	
36			37			7 X 600	
37			37			125 X 500 + 559	

THESIS DATA - TENSILE STRENGTH OF NEAT CEMENT - C.S. Jarvis, 1906

No.	Kind of Cement	Age in days Consistency	TENSILE STRENGTH, Lb. per sq. in. Direct	Average	Repeated		Remarks
38	Iola	Normal 1	115				
39		22.9% 1	115				
40		1	147				
41		1	144	130			
42		1			2 X 102#		
43		1			47 X 102#		
44		7	658				
45		7	580				
46		7	530	589			
47		7			31 X 500#		
48		7			43 X 500#		
49		7			6 X 500#		
50		50	753				
51		50	670	711			
52		50			2 X 650#		
53		50			5 X 260#	+ 820#	
54		50			25 X 500#	+ 880#	
55	Iola	Normal 1	146				Retempered after Initial Set
56		22.9% 1	140				at 3¼ hr.; from previous batch.
57		1	150	145			
58		7	590				
59		7	620	605			
60		7			10 X 500#		
61		7			9 X 500#		
62		50	847				
63		50			10 X 500# +	843#	
64		50			7 X 700#		
65		50			2 X 760#		
		50					

THESIS DATA - TENSILE STRENGTH OF NEAT CEMENT - C.S. Jarvis, 1906

No.	Kind of Cement	Consistency	Age in days	Tensile Strength, Lb. per sq. in. Direct	Average	Repeated		Remarks
66	Iola	24.9%	1	60				
67			1	59				
68			1	55	58			
69			1			15 X 30#		
70			1			14 X 30#		
71			1			21 X 30#		
72			7	375				
73			7	459				
74			7	476	437			
75			14	509				
76			14	737				
77			14	614	620			
78			14			59 X 450#		
79			14			77 X 450#		
80			49	747	747			
81			49			10 X 500# +	731#	
82			49			100 X 500# +	874#	
83			49			10 X 600# +	810#	
84	Iola	—	1	60				Retempered from previous
85			1	68	64			batch to normal consistency
86			1			23 X 35#		after 5 hr., at initial set.
87			1			31 X 35#		
88			7	443				
89			7	462	452			
90			7			400 X 250#		
91			14	621	621			
92			14			88 X 450#		
93			14			110 X 450#	+690#	
94			49	622				
95			49			10 X 500# +	740#	

THESIS DATA – TENSILE STRENGTH OF NEAT CEMENT – C. S. Jarvis, 1906.

No.	Kind of Cement	Consistency	Age in days	Tensile Strength, Lb. per sq. in. Direct	Average	Repeated		Remarks
96	Universal	Normal	95	845				Briquettes No. 96 to No. 127
97		24%	95	930				were kept in the molds in
98			95	896	890			moist air for 1 day, then in
99			95			10X500# +	860#	water, average temperature
100			95			10X600# +	820#	about 75° Fahr. for 3 weeks,
101			95			10X700# +	830#	then in dry air until tested.
102			95			10X700# +	905#	
103			95	———		10X700# +	890#	
104	Alma	~~Normal~~	99	600				
105			99	560	580			
106			99			10X400# +	589#	
107			99	———		50X400# +	530#	
108	Alma	———	101	633				
109			101	603	618			
110			101			10X500# +	608#	
111			101			2X500#		
112			101	———		10X500# +	598#	
113	Alma	———	100	1088				Stress applied very gradually,
114			100	840				reaching 1088# in 5 minutes.
115			100	807	823			Time used in applying other single
116			100			10X500# +	938#	loads, ½ minute to 1 minute,
117			100			10X500# +	1098#	for this set.
118			100	———		10X700# +	824#	
119	Vulcanite	———	101	500				
120			101	578	539			
121			101	———		10X400# +	677#	
122	Vulcanite		100	760				Stress applied very gradually.
123			100	699				
124			100	620	660			
125			100			10X500# +	635#	
126			100			10X550# +	680#	
127			100			10X500# +	650#	

THESIS DATA – COMPRESSIVE STRENGTH OF NEAT CEMENT – C. S. Jarvis, 1906

No.	Kind of Cement	Consistency	Age in days	Compressive Strength, Lb. per sq. in. Direct, 2" Cube	Repeated	Direct, 1" Cube	Repeated	Remarks
1	Universal	Normal	1	1220				Cubes No. 1 to No.
2		24%	7	4570				52 were molded and
3			7	5150				kept with Briquettes
4			64	8820				No. 1 to No. 95.
5			64	7960				
6			64		7500+7150			In repeating stresses
7			64	——	4X6700			the minimum is nearly
8	Vulcanite	Normal	1	625				5% of the maximum.
9		22.7%	1	705				
10			7	6320				
11			7	——	5000+5900			
12			52	8810				
13			52	——	10X7500+8750			
14-15			62	8620	6000+6500			
16-17	Iola	Normal	1	1120		1130		
18-19		22.9%	1	1030		1160		
20			1	1050				
21-22			7	5860		8000		
23			7	5100				
24-25			51	8020		14500		
26			51	——		15600.		
27-28	Iola	Normal	1	1226		1351		Retempered from
29-30		22.9%	7	6700		8000		previous batch after
31-32			51	8737		14000		Initial Set at 3½ hr.
33			51	——			10X11500+14000	
34-35	Iola	24.9%	1	340		442		
36-37			1	370		468		
38-39			7	3560		4375		
40-41			7	3240		3700		
42-43			50	7520		12000		
44-45			50	——	5250+7410		5X10600	
46-47	Iola	——	1	330		418		From previous batch,
48-49			7	4250		3400		retempered to normal
50-51			50	7050		11000		consistency after 5
52			50				3X9500	hr. at Initial Set.

THESIS DATA — COMPRESSIVE STRENGTH of NEAT CEMENT — C.S. Jarvis, 1906.

No.	Kind of Cement	Consistency	Age in days	Compressive Strength, Lb. per sq. in. Direct	Load applied in minutes	Average	Repeated	Remarks
53	Universal	Normal	97	9400	3			Cubes No. 53 to No. 82 were all
54		24%	97	8500	3			1" cubes, and were molded and
55			97	8460	3	8790		Kept with Briquettes No. 96 to 127.
56			97	6000	$\frac{1}{6}$			
57			97				207X4300#+11200#	
58			97				600X4300#+11000#	
59			97	———			11400#	After sustaining 5000 lb. for
60	Universal	$26\frac{1}{4}$%	103	10500	3			13 hr.
61			103	10450	3	10475		
62			103				24X8000#+13000#	
63			103	———			11900#	After sustaining 8000 lb. $2\frac{5}{6}$ hr.
64	Alma	—	104	10700	3			
65			104	8500	$2\frac{1}{2}$			
66			104	10500	$4\frac{1}{2}$			
67			104	9000	3			Sustained 9000# 2 min., then failed
68			104	7775	4	9295		
69			104				10300	After sustaining 8000# for 17 hr.
70			104	———			13475	" " 8800# for $2\frac{2}{3}$ hr.
71	Alma	—	103	12000	$2\frac{1}{2}$			
72			103	11450	$2\frac{1}{2}$	11725		
73			103				127X10500#+11000#	
74			103				400X6000#+10500#	
75			103				43X9000#	
76			103	———			250X10000#+12470#	
77	Alma		99	17000	4			
78			99	15900	3			
79			99	15150	5	16017		
80			99				48X13000#+18000#	
81			99				16180	After sustaining 13000# $1\frac{1}{2}$ hr.
82			99				16350	" " 14000# $4\frac{1}{2}$ hr.

TESTS of CONCRETE-STEEL BOND, under REPEATED STRESSES

THESIS DATA

C.S. Jarvis, 1906

No.	Size	Age in Days	Cement	Steel	Bond, in lb. per sq. in.	Tension in Steel, lb. per sq. in. Initial	Maximum	Previous Stresses Bond	Steel	Remarks
1	6″	115	Vulcanite	Johnson 3/4″	214	0	5900	254	34980	When loads are removed, the minimum stress is about 5% of the maximum.
2	6″	″	″	″	258	0	8300	0	0	
3	6″	90	Universal	Round 3/4″	197	0	6300	13X210	13X6800	
4	6″	″	″	Rogers-Sh.	280	0	18400	0	0	
5	6″	52	″	Ransome 3/4″	180	20000	31500	0	0	
6	6″	″	″	″	132	″	28440		10X20,000+28,400	
7	6½″	51	Alma	″	340	″	111400	0	0	Rod and bond failed at once.
8	6½″	51	″	″	322	″	49222	0	10X20,000	
9	6½″	51	″	″	248	30000	47160	0	9X30000+44000+49700	
10	6½″	53	″	″	312	″	51540	0	0	
11	6″	51	″	Rogers-Shears 1/4″ section	142	16000	25350	0	0	
12	6″	51	″	″	142	″	25350	0	10X16000	
13	6″	53	Iola	Johnson 3/4″	182	20000	25840	0	0	
14	6″	53	″	″	108	″	23480	0	3X30000	
15	6″	55	″	″	94	″	23040	0	10X30000	
16	4″	43	″	Ransome 3/4″	245	0	10400	0	0	
17	6″	45	″	Round 3/4″	272	0	8480	25X141	25X4500	
18	6″	45	″	″	212	0	6790	12X212	12X6790	
19	6″	35	″	″	201	0	6450	9X201	9X6450	
20	6″	37	″	″	254	0	7950	0	0	
21	6″	110	″	″	402	0	12900	0	0	
22	6¼″	40	″	Rogers-Sh.	166	25000	36440	0	30000+3X43000	
23	6″	52	″	″	373	0	24600	Sheared partly along corrugations, then split the block.		
24	6″	52	″	″	364	0	24000	″ ″ ″ ″ ″		
25	6″	52	″	″	337	0	22200	3X210+ 3X280+364	3X14000+ 3X19000+24000	
26	6″	52	″	″	345	0	22800	3X210+ 3X257+303	3X17000+ 3X17000+20000	
27	6″	62	″	Ransome 3/4″	317	0	20200	Applied within 3 min.		
28	6″	62	″	″	300	0	19100	″ ″ ″ ″		
29	6″	62	″	″	474	0	30300	5X183+5X233 +5X306+339	5X11600+5X14700+5X19300 +21400	Load causing failure applied gradually in [illegible] minutes
30	6¼″	17	″	″	101	22000	28710			
31	6¼″	17	″	″	248	24000	34160			
32	6″	17	″	″	201	26000	39280			
33	6″	17	″	″	145	30000	39560			
34	6¼″	17	″	″	111	34000	41639			
35	7″	31	″	″	495	0	36880			
36	7″	31	″	″	302	20000	42500			
37	6″	36	″	″	385	0	24600	5X111	5X7000	
38	6½″	40	″	″	355	20000	44550			
39	7″	52	″	″	619	0	46100	Load applied gradually in 30 min.		

Note. The above cubes were kept in dry air after molding, the temperature ranging from 44° to 95° Fahr.

W. K. Seitz
C. S. Jarvis 1906.

THESIS DATA – TESTS OF REINFORCED CONCRETE BEAMS

No.	Kind of Cement Portland	Age in days Percentage Steel	Days	Kind of Reinforcing	Maximum Loading Lb.	Compression in Concrete Lb.	Tension in Steel Lb.	Compression in Steel Lb.	Remarks
1	Alma	1.16%	71	Johnson ½"	23300	2250	36740		
2	Alma	1.16%	71	"	27500	2650	43200		
3	Vulcanite	1.16%	70	Rogers-Shears	19500	1895	30900		
4	"	1.16%	75	"	24700	2390	38960		Broken by repeated stresses.
5	Universal	0.91% 1.82%	70	Kahn, 3 Trusses	33200	2040	33470	22000	Steel in compression side was 0.91%; and in tension side, 1.82%
6	"	0.97%	74	Ransome Truss	25100	2570	47030		Actual percentage of steel, 1.56%; only 0.97% resisted tension.
7	Iola	0.66%	74	Ransome Bars	19900	2360	54230		
8	"	0.66%	74	"	16700	1990	45770		
9	"	0.91% 1.82%	74	Kahn, 3 Trusses	40900	2550	40650	26000	Broken by repeated stresses.
10	Universal	0.97%	75	Ransome Truss	31300	3190	58400		Broken by repeated stresses.

Span, 7½ ft.
Length, 8½ ft.
Breadth, 8 inches
Depth of Beam, 12"
Depth to center of gravity of steel, 10¾ in.
Distance between centers of gravity of steel in Beams No. 5 and 9, 9.1 inches.
Weight of Beam of Concrete, 800 lb.
Weight of overhead wooden beams, blocks, and tackle, 700 lb.
Bending Moment due to dead load, 7940 inch-lb.
Bending Moment due to one kip [1000 lb.] of applied load, 14500 lb.

Influence of Repeated Stresses in Concrete and Cement.

Conclusion.

From a study of the preceding data the following conclusions have some support:

(1) A small number of repetitions of from one-half to five-sixths of the breaking load will cause failure in cement up to one week in age. Reference, cubes No. 10 and 11; Briquettes No. 31, 32, 42, 43, 47, 48, 49, 60, and 61.

(2) Cement specimens more than two weeks old may have their ulitimate strength either raised or lowered by the influence of repeated stress, depending upon the age of the specimen, the percentage of breaking stress used, and the number of repetitions. Sustaining a steady load in many cases acts like repeating the stress.

References for strength diminished by fatigue, cubes No. 6, 7, 15, 45, 52, 67, 75.

Briquettes No. 9, 24, 30, 37, 52, 64, 65, 78, 79, 92, 111.

References for strength increased,

Cubes No. 57-59, 62, 63, 69, 70, 76, 80.

Briquettes No. 20-23, 53, 54, 82, 83, 116, 117, 121.

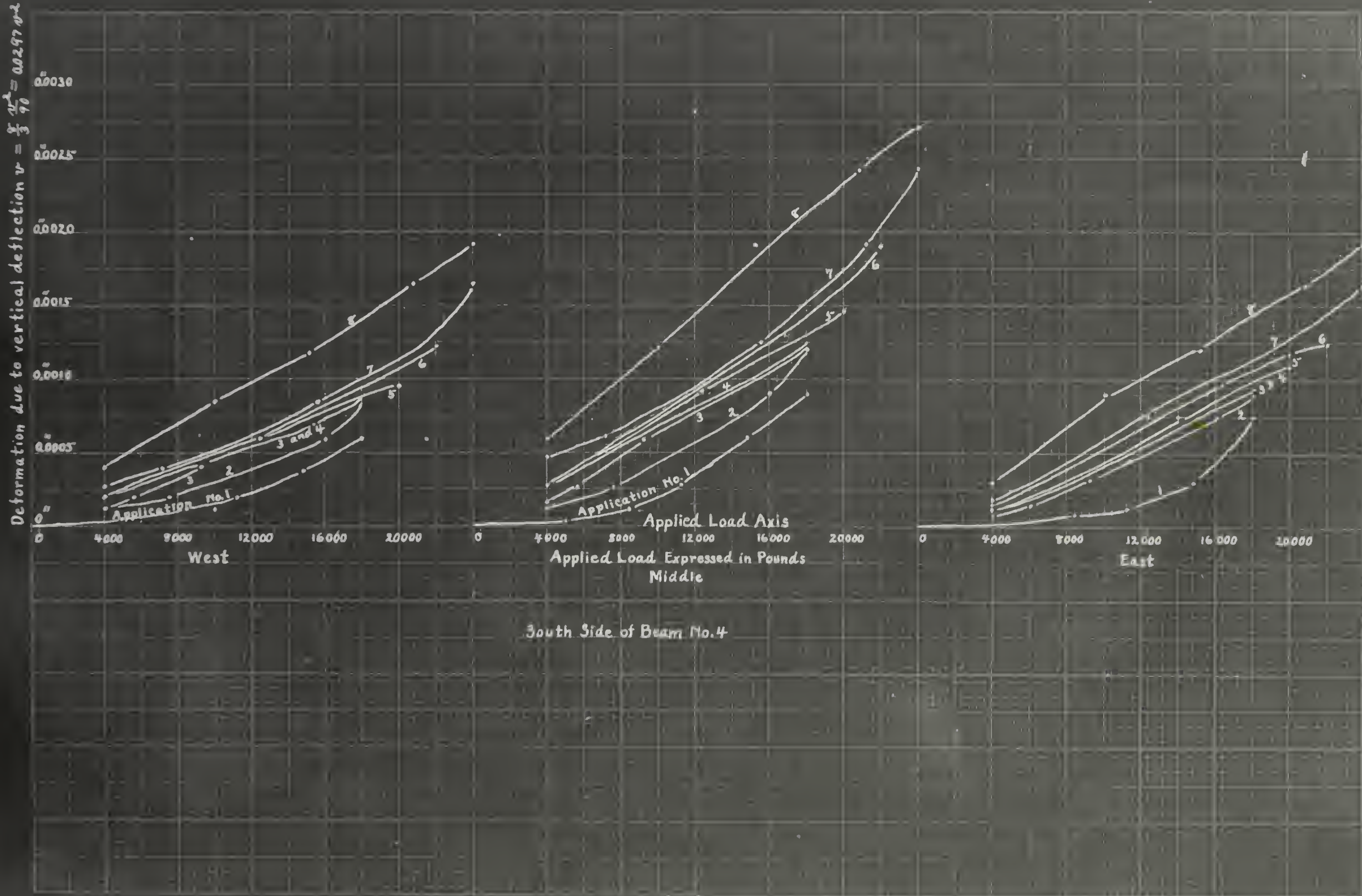
References for strength practically unaffected,

Cubes No. 13, 33, 73, 81, 82.

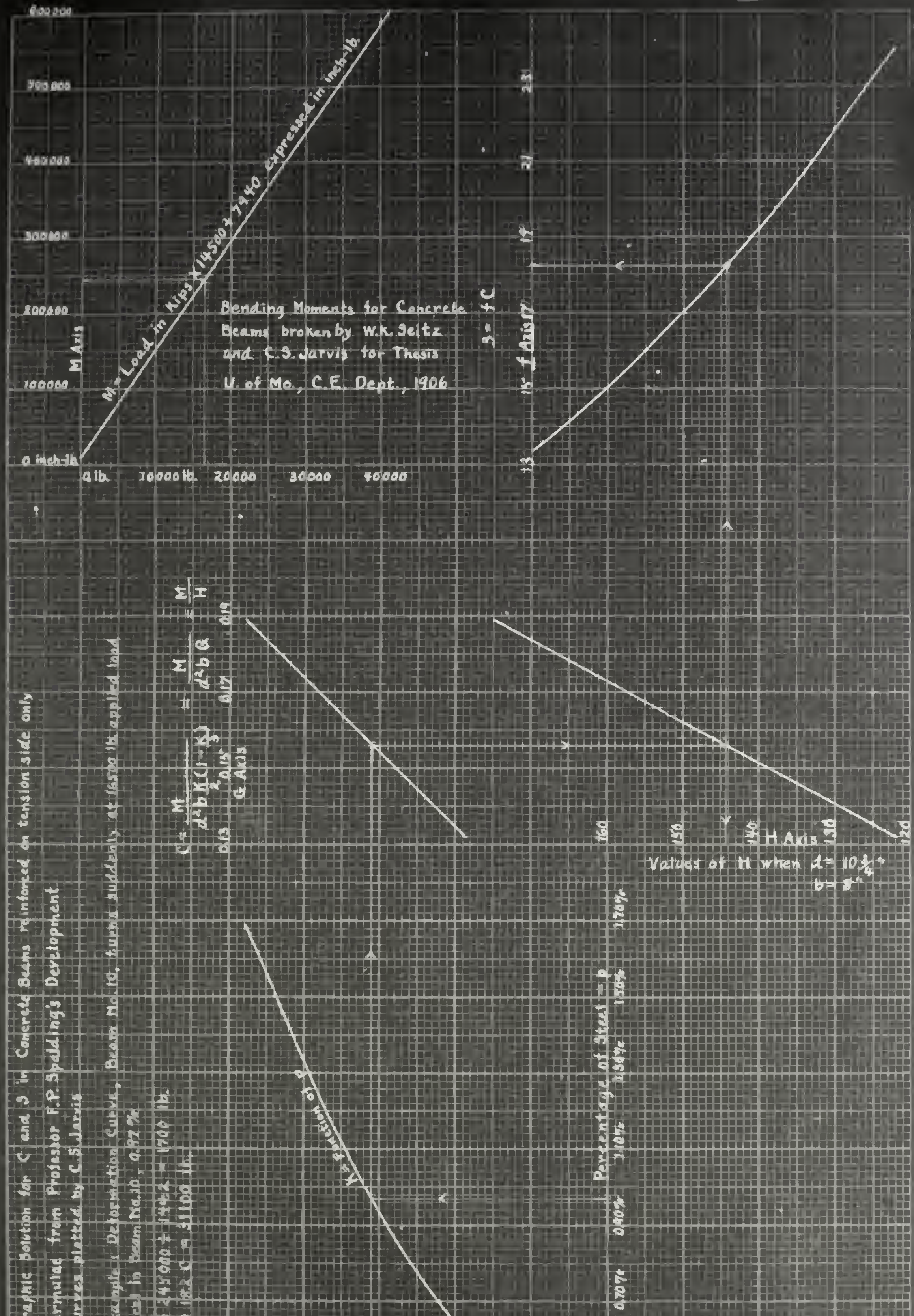
Briquettes No. 35, 81, 99-103, 106, 107, 110, 112, 118, 125-127.

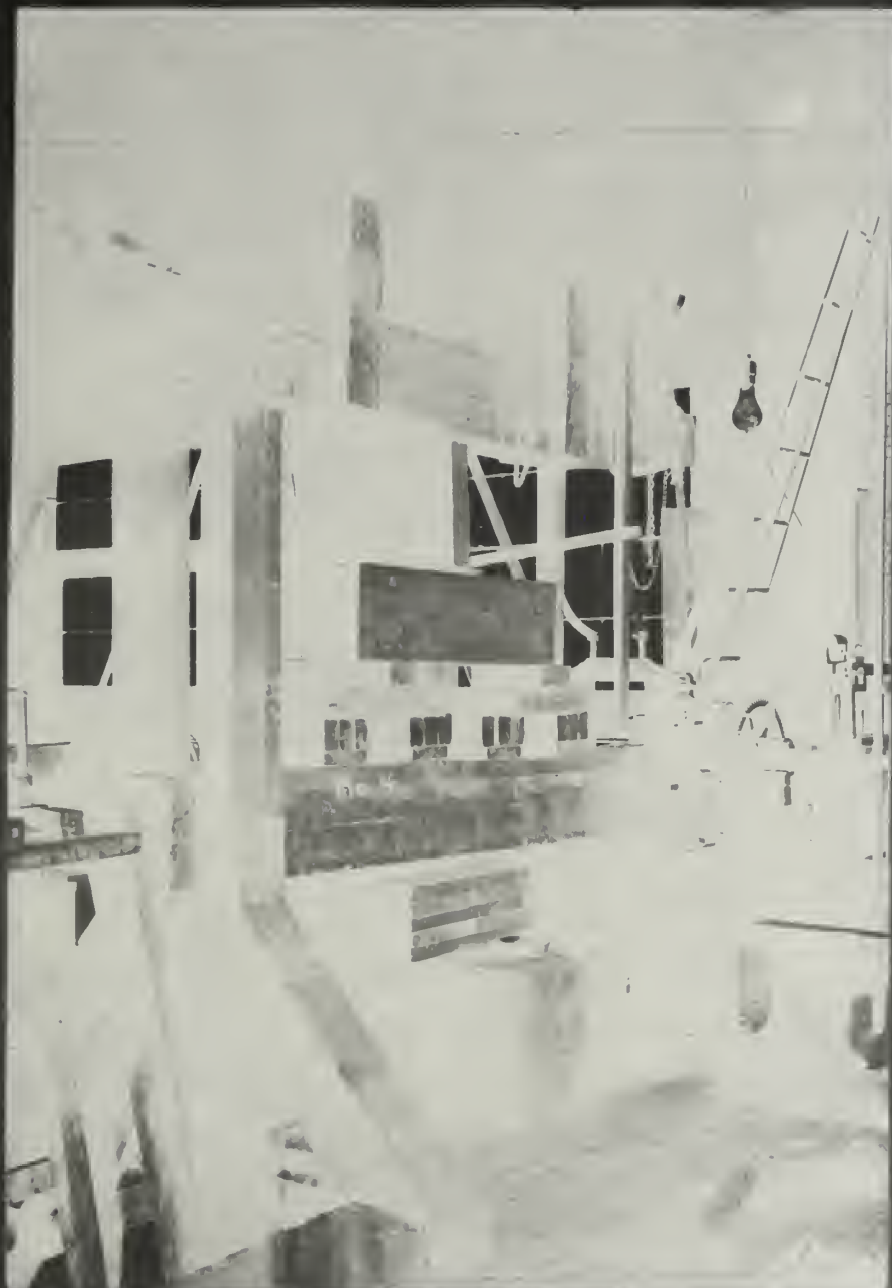
(3) The bonding strength of concrete on steel is impaired by stresses in the steel far within the elastic limit, whether the tension be applied before or during the bonding test.

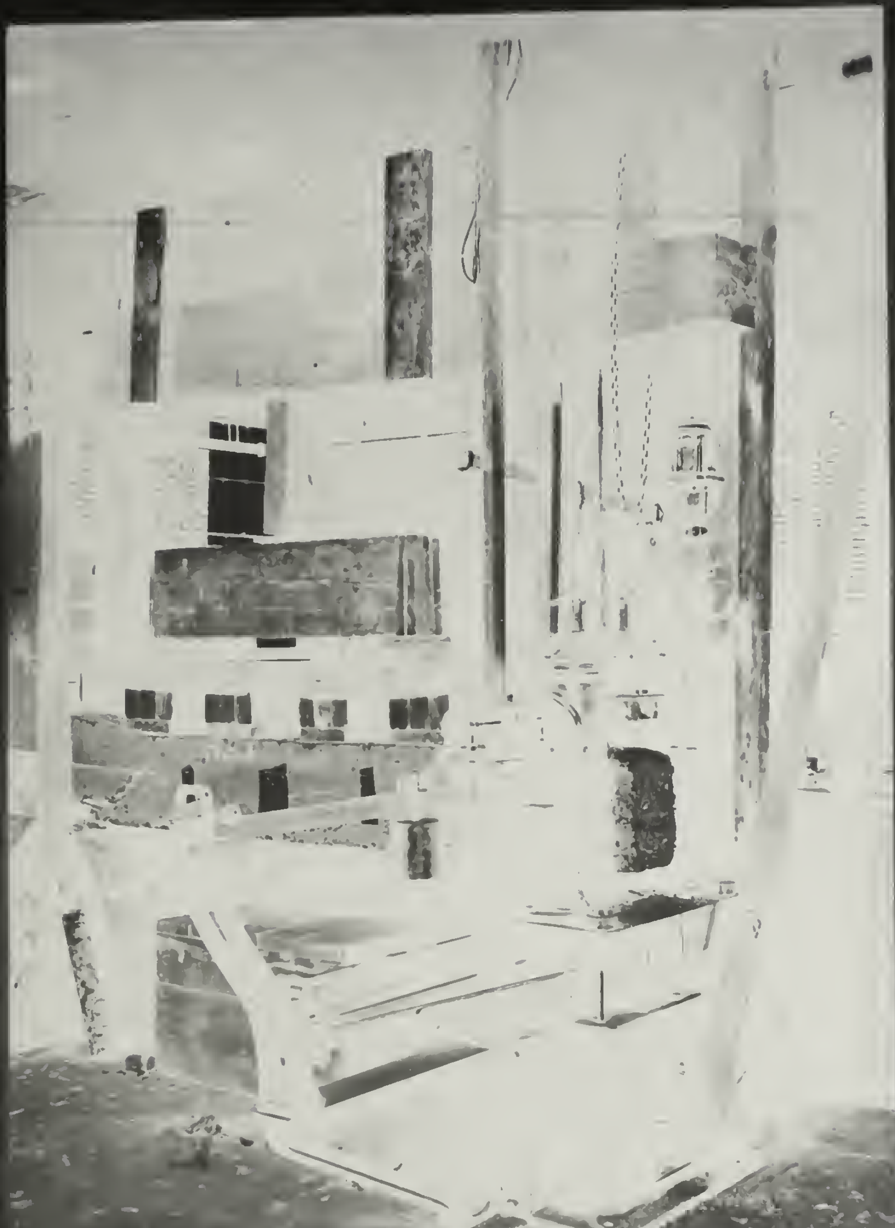
Blocks No. 8, 9, and 10; 11-15; 17 and 18; 19 and 20; and 32-34, if we consider each group separately, exhibit a tendency to release the bond at a constant maximum tension in the steel, if the members of each group are reduced to standard conditions. The initial tension in the steel was varied for some groups; therefore if a constant maximum tension is to be maintained for the steel, the bonding strength may be considerably impaired by the 14,000 or 16,000# tension in the steel used in practice.



South Side of Beam No. 4


Bending Moments for Concrete Beams broken by W.K. Seltz and C.S. Jarvis for Thesis
U. of Mo., C.E. Dept., 1906
M = Load in Kips X 14500 + 7940 expressed in inch-lb.
M Axis
0 inch-lb
100000
200000
300000
400000
500000
600000
0 lb.
10000 lb.
20000
30000
40000
S = f C
f Axis
13
15
17
19
21
23
Graphic Solution for C and S in Concrete Beams reinforced on tension side only
Formulas from Professor F.P. Spalding's Development
Curves plotted by C.S. Jarvis
Example: Deformation Curve, Beam No. 10, fails suddenly at 14500 lb applied load
Steel in Beam No. 10, 0.82 %
C = 245 000 ÷ 144.2 = 1700 lb.
S = 18.2 C = 31100 lb.
C = M / d²bK(1 − K/3) = M / d²bG = M / H
G Axis
0.13
0.15
0.17
0.19
H Axis
160
150
140
130
120
Values of H when d = 10¾", b = 8"
K = Function of p
K Axis
0.45
0.40
0.35
0.30
0.25
0.20
Percentage of Steel = p
0.50%
0.70%
0.90%
1.10%
1.30%
1.50%
1.70%
K = Cr / (Cr + S)
z = Kd
Assume r = 10





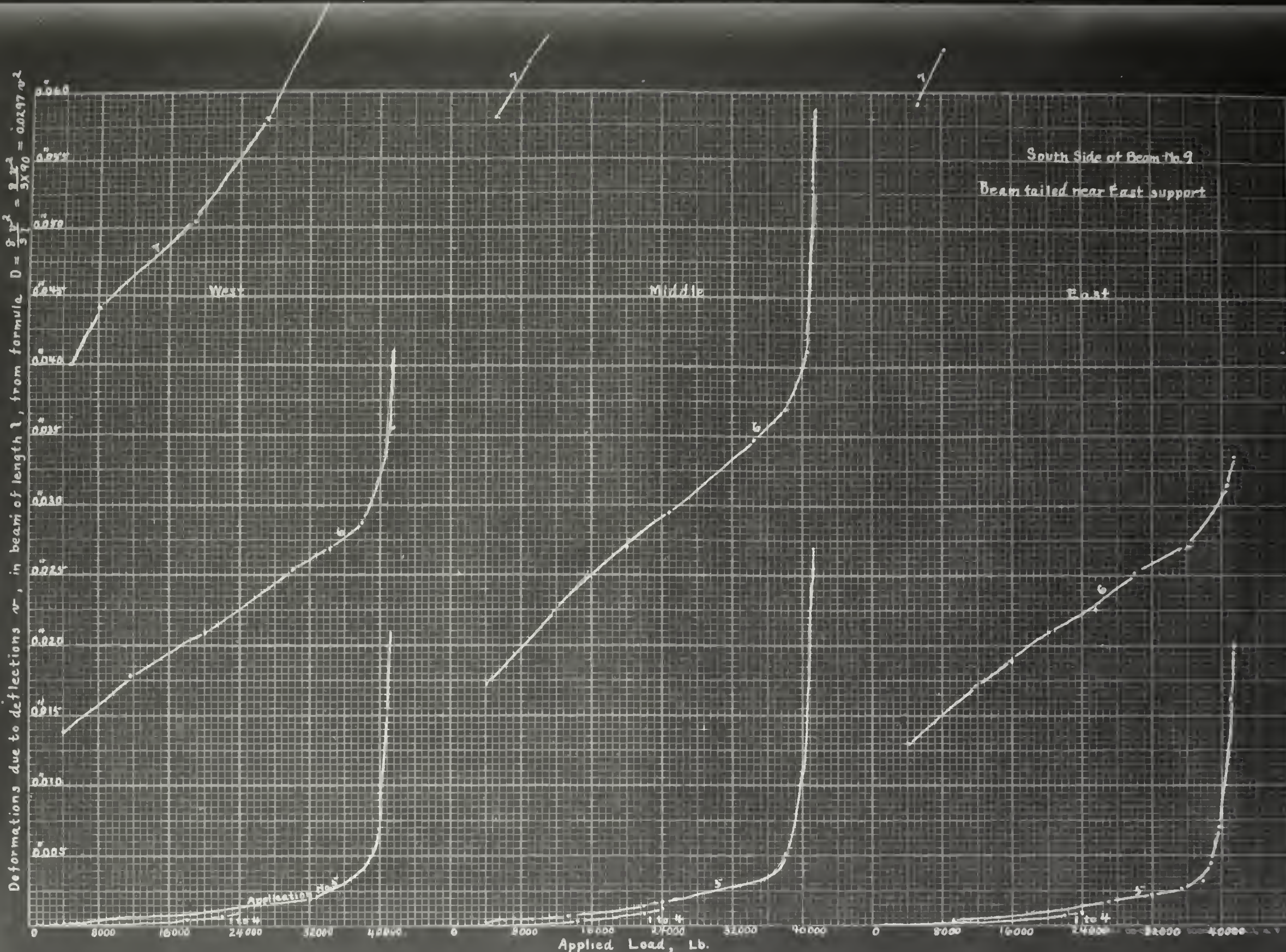
Conclusions.

(4) The curves showing the deformations of beams No. 4, 9, and 10 illustrate most clearly the need of a high elastic limit in the steel used for reinforcement. Only the middle curves show accurately the deformations; the east and west points were 16 inches from the center, therefore the deformations computed from deflections at these points are useful mainly to observe the symmetry of the curve assumed by the beam.

For Beam No. 4 the successive applications produced but a slight permanent set until the sixth load, under which the stress in the steel was 33,600#, and the maximum compression in the concrete, 2150# per square inch. During the eighth loading the curve became nearly a straight line showing that no slipping along the rods was taking place. The previous stresses had seemingly taken up all deflections except such as were caused by actual deformation of concrete and steel. Shrinkage in the concrete while maturing may account for the slight slipping of the rods under the first severe strains.

A diagonal check had developed near the support at the seventh application. After the eight load had been applied and the machine was stopped, the beam broke where the

check had begun to develop. The rods had slipped at the end thus allowing tension in the concrete.

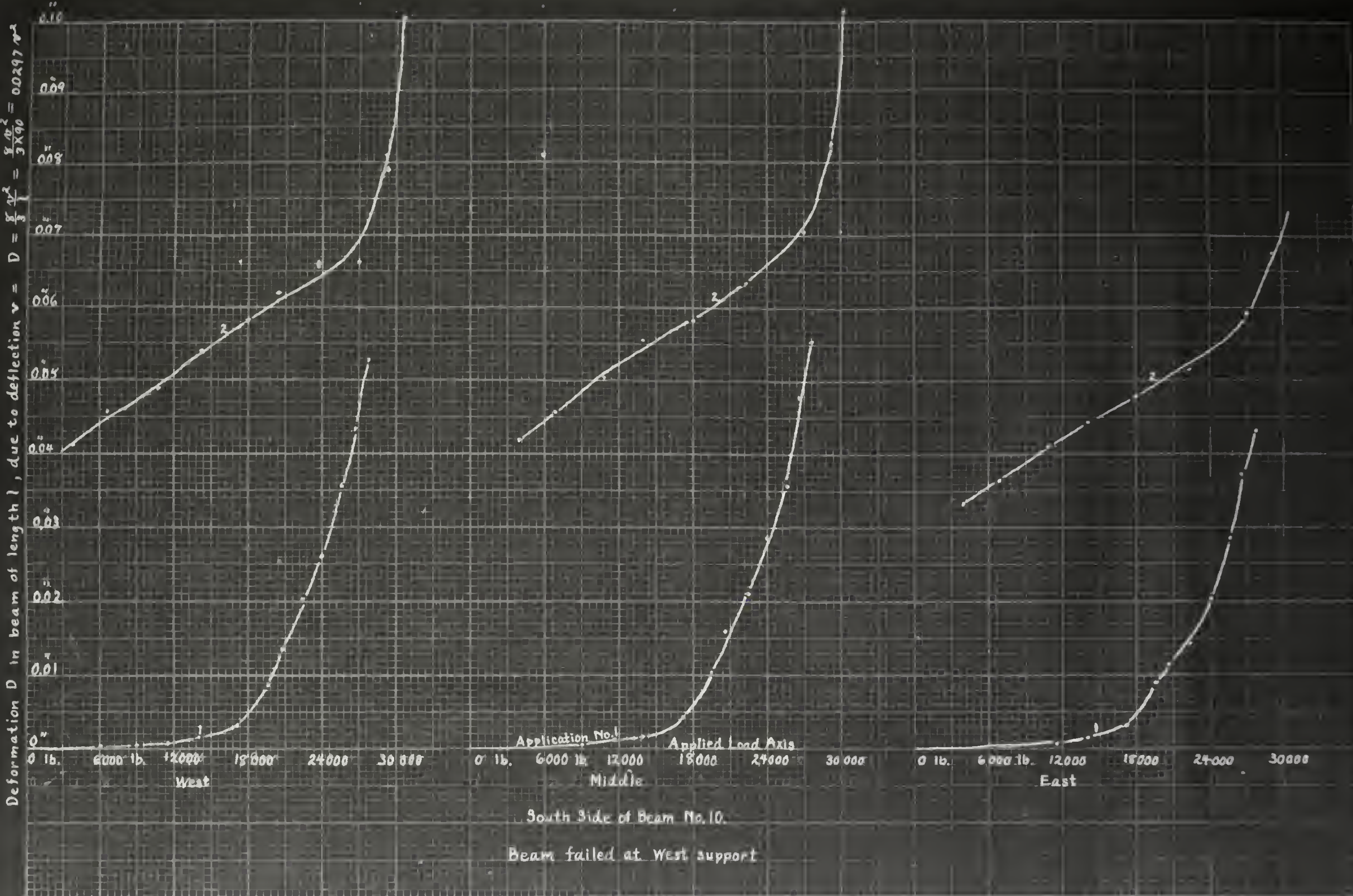


South Side of Beam No. 9
Beam failed near East support
West
Middle
East
Application No. 5
1 to 4
5
6
7
Deformations due to deflections v, in beam of length l, from formula $D = \frac{8v^2}{3l} = \frac{8v^2}{3 \times 90} = 0.0297\,v^2$
Applied Load, Lb.
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0
8000
16000
24000
32000
40000


No 5

Conclusions.

(5) The deformations curves for Beam No. 9 nearly coincide for the first five trials, until the applied load was 36,000#, the tension in the steel in the lower part of the beam 35,850#; the compression in the upper steel 23,000, and in the concrete 2250#. At this point there is a somewhat abrupt turn in the curve, as though the anchorage was giving way; cracks became visible in the beam near the middle of the tension side; the permanent set received at this loading would also indicate that the anchor strips had either slipped or stretched slightly. During the sixth application the strain seems to be nearly proportional to the stress until the load is 40,000#, then the slipping seems to have had a new impetus, and the beam had practically failed, although it withstood a slightly greater load after this. The cracks had become visible, and grew larger when the seventh load was applied up to 40,900#. At this point the deflection was excessive, being one and three-fourths inches at the center of the beam; and although this was increased a half inch, the reaction on the machine gradually decreased to 19,000#, showing that the resisted load was 38,000#.


Deformation D in beam of length l, due to deflection v = D = 8/3 v²/l = 8v²/(3×90) = .00297 v²
0.10"
0.09"
0.08"
0.07"
0.06"
0.05"
0.04"
0.03"
0.02"
0.01"
0"
0 lb.
6000 lb.
12000
18000
24000
30000
West
Middle
East
Application No. 1
Applied Load Axis
1
2
South Side of Beam No. 10.
Beam failed at West support

Conclusions.

(6) Beam No. 10 deflected more readily than No. 9, the point at which the slipping of the anchorage began being at 16,500#, corresponding to a tension in the steel of 31,000# per square inch, and a maximum compressive stress of 1700# At this time cracks became visible near the middle of the beam and also near the east support. It will be noticed that during the second application the curve become nearly a straight line which passes slightly higher at 16500# load than the end of the first deformation curve, which corresponds to 27,800# applied load. This illustrates in a marked degree the decrease in strength caused by repeating a stress nearly equal to the modulus of rupture.

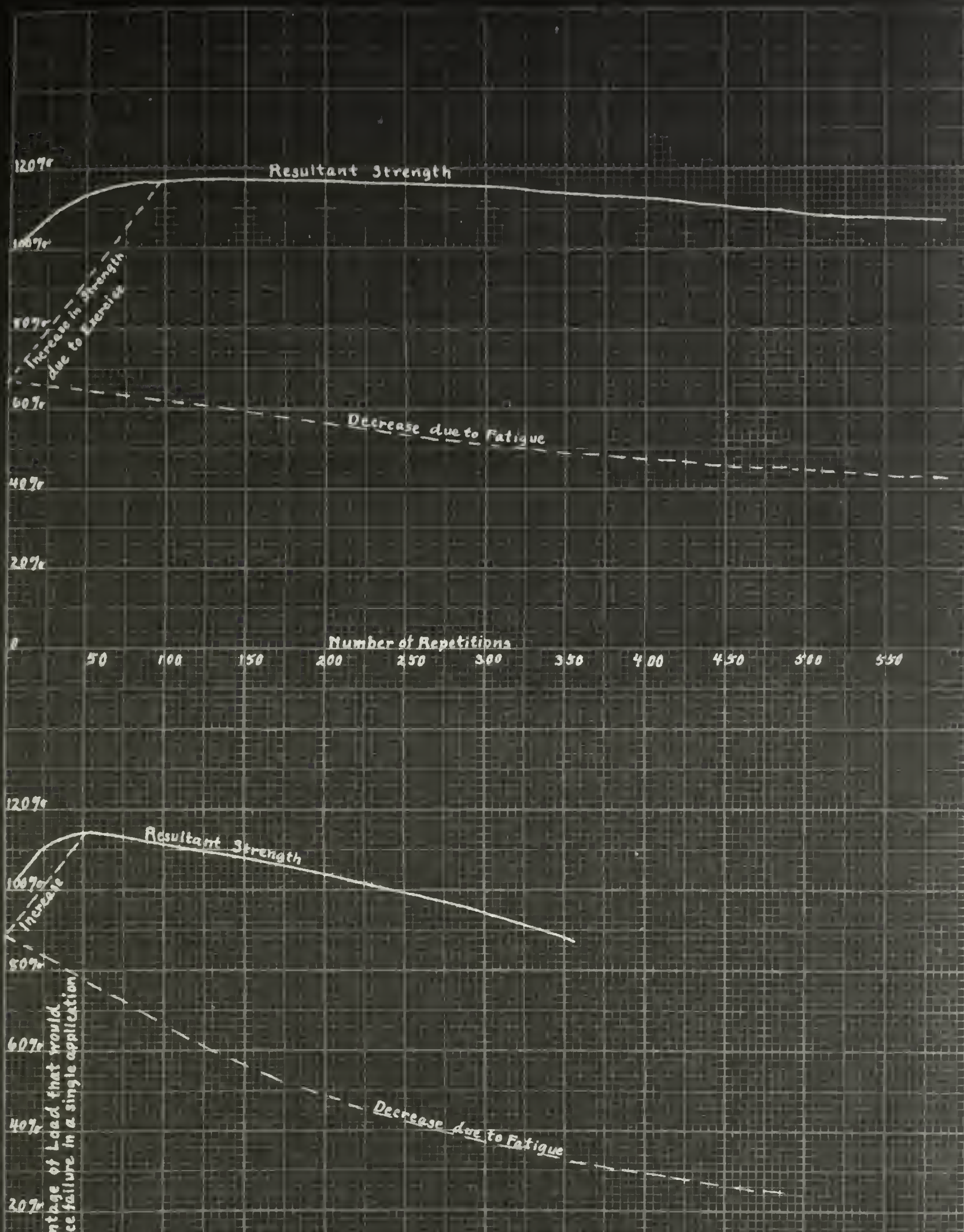
During the second application the beam failed along a diagonal line near the west support, extending upward toward the middle. At rupture, the tension in the steel was 58,400#; and the maximum compression in the concrete was 3,200#.

(7) The results of bonding tests and the behavior of reinforced concrete beams point clearly to the advantage of using rods that may be firmly anchored. The adhesive strength of concrete seems to be diminished in nearly every case by the previous stresses in either the steel or the

the concrete, hence a mechanical bond is advisible. No doubt a much higher strength would have been developed if the beams had been longer, the parts extending over the support furnishing an additional bonding area.

The Kahn trussed bar seems to be the best type of reinforcement for the beams tested. Even after failure, the beam was capable of supporting nine-tenths of the breaking load for several minutes.

(6) The apparent contradictions observed in the behavior of fairly well matured cement specimens after sustaining repeated or continuous stresses are probably due to the combined effect of two influences, the one tending to increase the ultimate strength, which may possibly compare with the influence observed in cold-rolling steel; the other tending to decrease the modulus of rupture through fatigue. It would be hazardousto try defining these two laws with the meager data that is available, but I have drawn curves which may be suggestive of the general effect produced by moderate exercise within two-thirds of the breaking stress; and the fatigue induced by higher stresses.



Suggested General Form for Curves showing the Influence of Repeated Stresses in Cement.

U. of Mo. C.E. Dept.
Thesis

C.S. Jarvis,
1906